

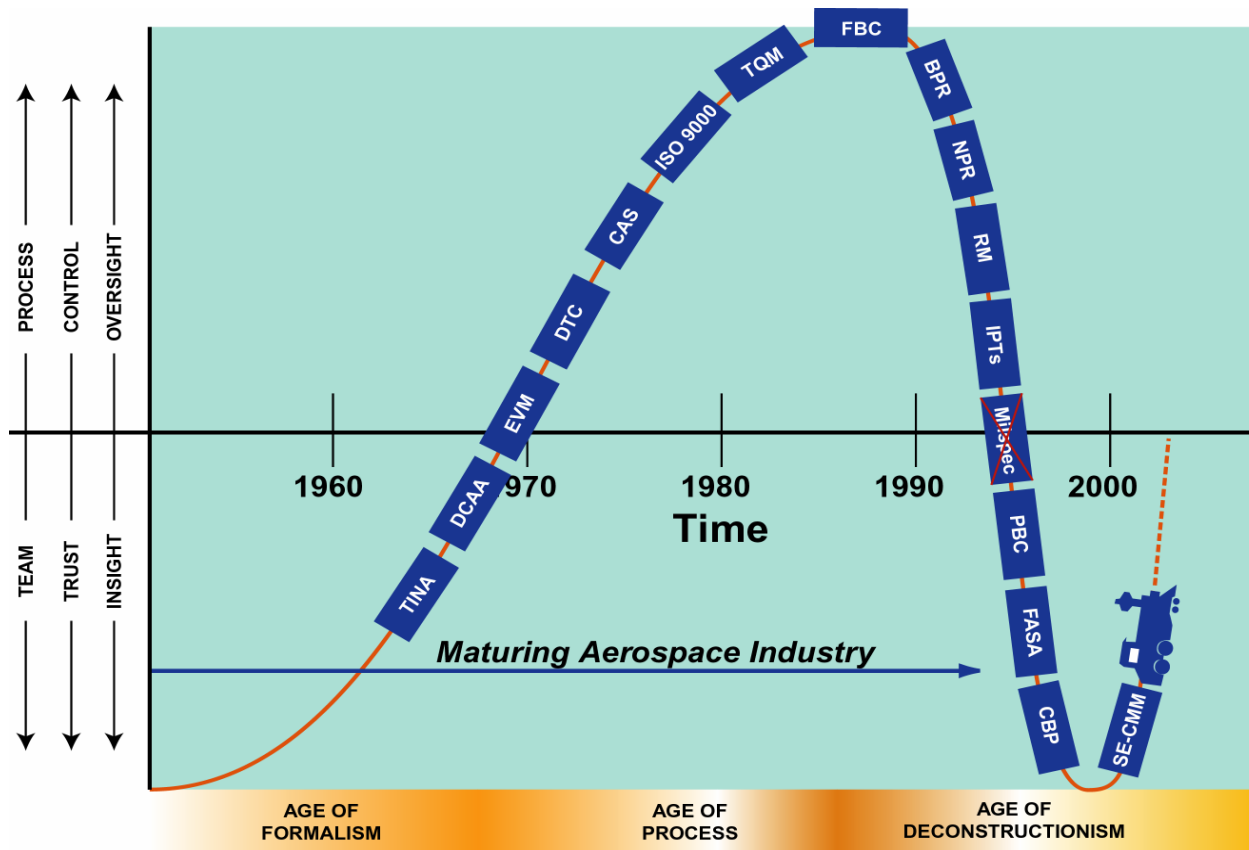
# *Current Trends in T&E*

**William F. Tosney**

# *Overview*

- **Background**
- **Near-Term History Assessment**
- **Refocus on Systems Engineering**
- **T&E Trends and Issues**
- **Current Initiatives and General Conclusions**

# *The Roller Coaster of “How to” Trends*



Source: The Application of Best Practices to Space Vehicles, RANS Study, May 2000

*Successful Programs Avoid Extreme Trends*

# ***Background***

- **The 90's Saw “Radical New Directions” for Space System Development (*“to save \$\$\$”*)**
  - DoD *“Acquisition Reform”*
  - NASA *“Faster, Better, Cheaper”*
  - Commercial *“Best Practices”*

*Improving the Development Process Is a Laudable Goal.  
How Well Were Inherent Risks Understood?*

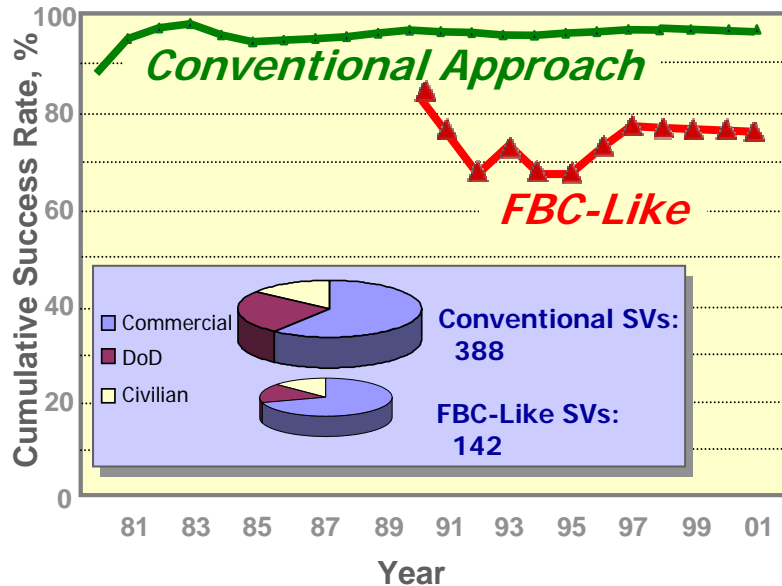
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# Decrease in Overall Satellite Quality

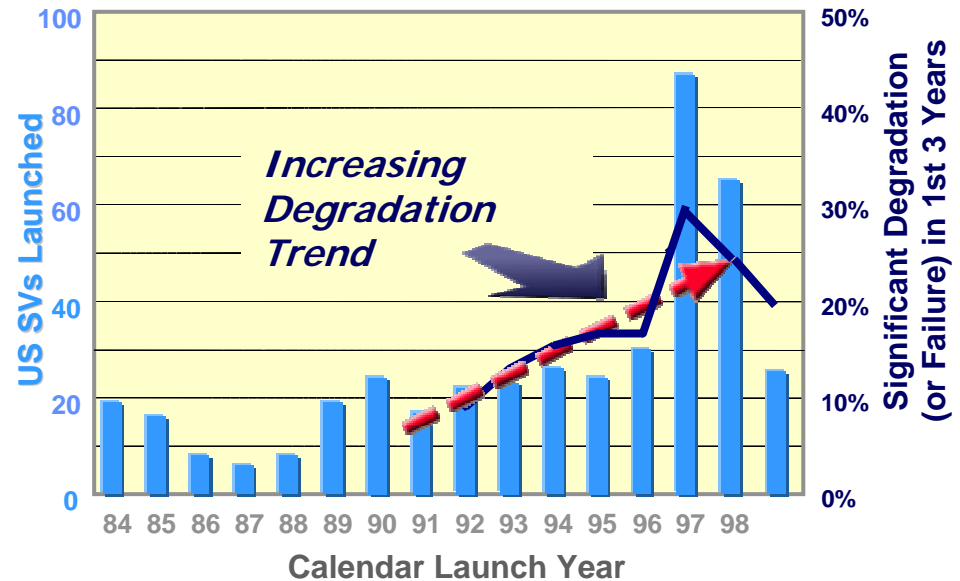
## 1st Year Catastrophic Failures

- 454 SVs -



## 1st Year Catastrophic Failures and 3 Year Degradation

- 394 SVs -

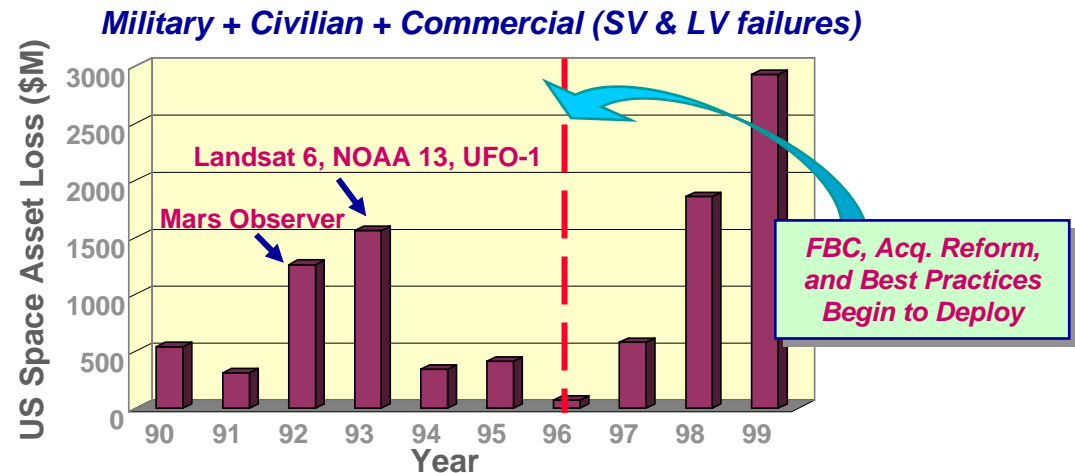


*Cost and Schedule Savings on the Ground  
Are Far Outweighed by Lost Opportunity*

# *A Critical Need Exists to Better Understand Risk Issues and Their Relationship to T&E*

- **Mishaps Occur Too Often and Are Repeated**

- Success rates are stuck in low-90% levels
- Over \$12 Billion in lost assets since 1990
- Best practices and lessons are compartmentalized at best



- **Programmatic Insight Is Varied**

- Acquisition reform roadmap unclear
- “Program centric” and increasingly constrained
- Loss of heritage data and lessons a reality

- **Better Disciplined Systems Engineering Processes and More Effective Industry-wide Technical Communication of Issues Are Key to Improving Mission Success**

# ***Industry-wide Trends***

- **Declining Quality, Safety, and Systems Engineering Are not Unique to the Space Industry**
- **AF Implemented Policy on Operational, Safety, Suitability, and Effectiveness (OSS&E) as Result of Numerous Mishaps**
  - B1B mishap traced to a flawed re-design
    - » Loss of technical oversight and communication between contractors
  - T-3A Firefly mishap traced to marginal design and qualification (6 deaths)
    - » Procured as COTS product
    - » Loss of technical oversight and intentionally abbreviated testing





# *Space Industry Re-calibrates*

Launch Vehicle BAR:	Re-emphasize <u>oversight vs. insight</u>
Boeing Review:	<u>Quality</u> must be the highest priority
L-M Review Team:	Rigorously <u>“test like you fly”</u>
NASA Mars Panel:	<u>“Mission Success First”</u> - a cultural shift
NASA FBC Review:	Too many mission failures failed to adhere to <u>established standards</u>
RAND Study:	FBC - an <u>uncontrolled experiment</u>

*Space Is a High Risk, Craftsmanship Industry and Veering Away From Proven Processes is a Costly Gamble*

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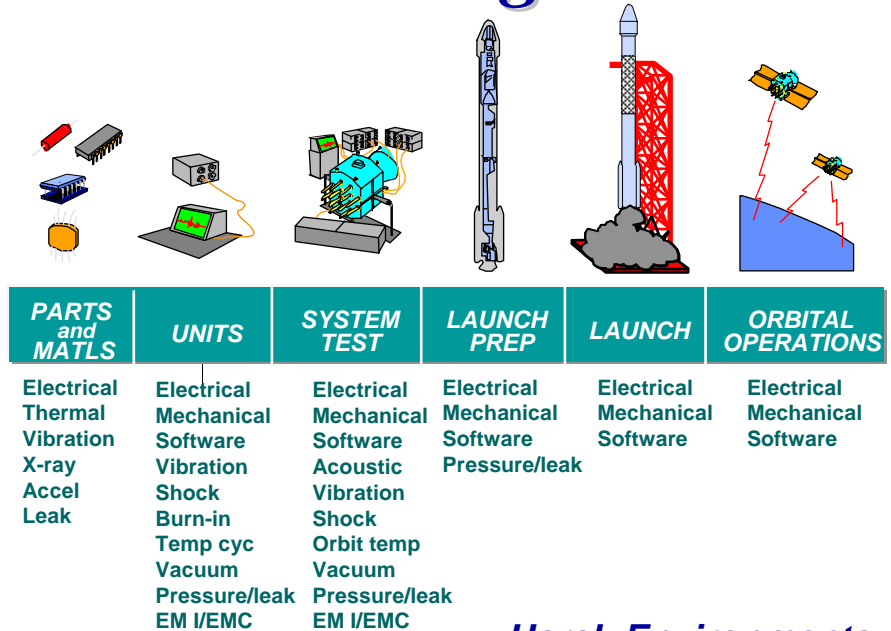
# ***Root Cause – “Why Things Went Awry?”***

- **Acquisition Agents Relegated to a “Trust and See” Role**
  - Risk, especially development, transferred largely to contractors (TSPR)
  - Systems are becoming increasingly more complex
  - Commercial space market and contractors cannot carry the burden alone
- **Cost and Schedule Became the Focus of Risk Management**
  - Deviation from conventional practices (CAIV)
  - Reduced oversight at contractors is a major issue with insurance brokers
- **Systems Engineering and Test Disciplines Greatly Eroded**
- **Specs and Standards Loosely Applied**
- **PMP Quality and Review Processes *Dramatically* Curtailed**
  - Reductions in government oversight were not mitigated by contractors as intended (especially at subcontractor level)
    - Major reductions in DCAA, Gov't, contractor, and subcontractor oversight
  - MA largely decoupled from design process
    - MIL-HDBK-217 / FMECA / PRA considered “burdensome”
    - Vigorous pedigree reviews “off the table”

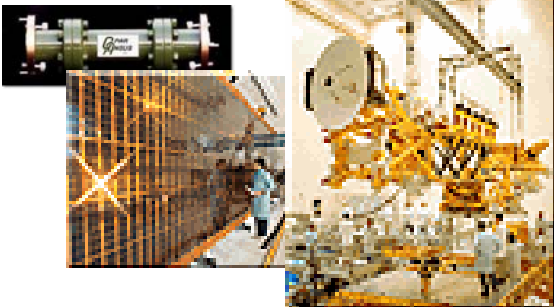
# Disciplined Systems Engineering Is Key to an Effective T&E Program

## Factors Influencing Test Perceptivity:

- Analytical prediction accuracy
- Testability
- Interfaces
- Selected measurements
- Measurement uncertainty
- Test equipment limitations
- Multiple environments
- Integration effects

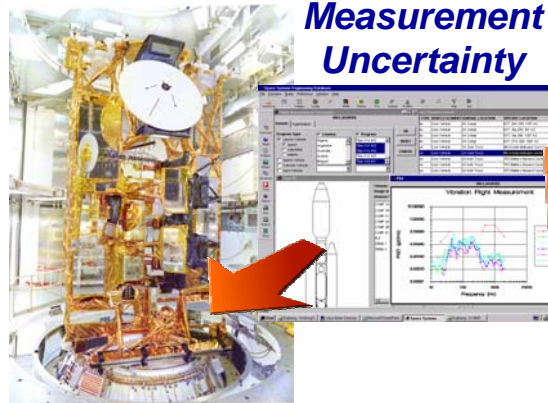


## Multiple Subcontractors

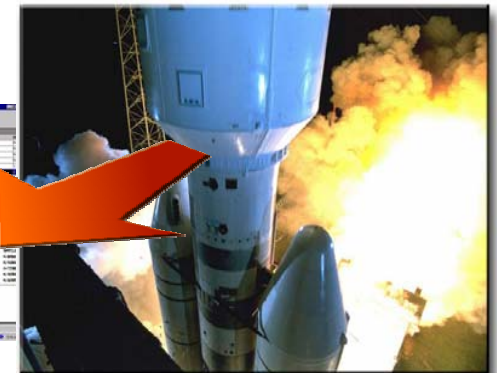


## Complex Integration

## Measurement Uncertainty



## Harsh Environments



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# ***Major Efforts Are Underway to Reinvigorate Systems Engineering***

- **SMC and NRO Are in the Early Phases of Reinvigorating SE**
  - System architecture and acquisition planning
  - Program management, development and engineering oversight
- **Improving SE and Development Processes Requires Some Insight and Knowledge Gained From Experience**
  - Planning, development, production, and process modeling solutions should evolve from proven methods and with full anticipation of growing risk areas
    - Engineering insight is essential (anyone can reduce cost & schedule)
    - Optimize SE processes for “defined” mission success (this is not a mass production industry)
    - An “overnight” or “one-fix” solution is not likely
- **Evaluating Acquisition/Development Models From Successful and Failed Programs is Key**
  - Develop a modeling strategy based on key influencing variables
  - Determine the most perceptive SE and mission assurance practices
- **Mission Assurance and Risk Management Are Becoming a Much More Integral and Disciplined Part of SE**
  - Process “health status” metrics (based on cost, schedule, performance and risk)
  - Independent assessment of design margin erosion

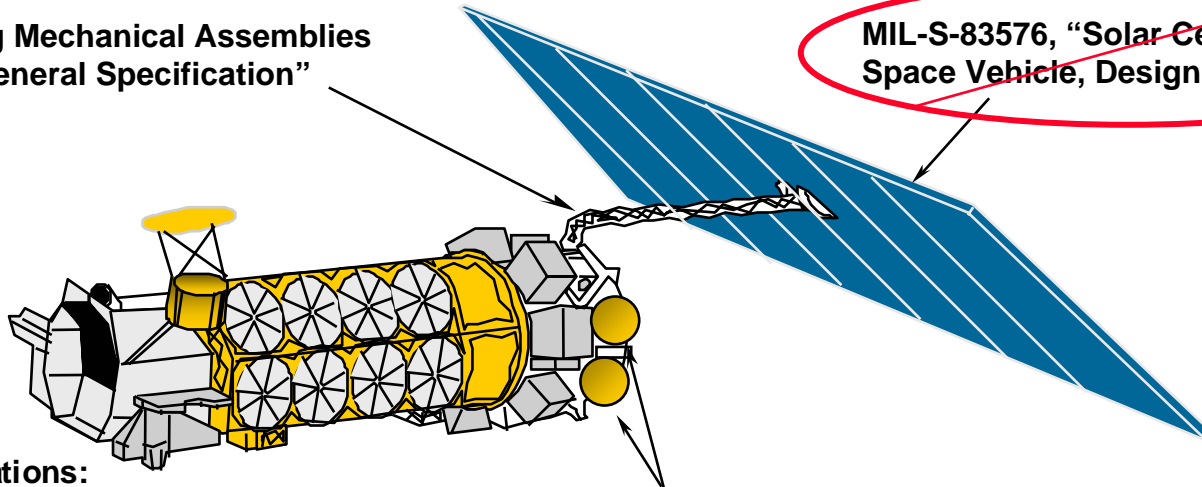
# *Conventional Test Best Practices*

- MIL-HDBK-340, “Test Requirements for Space Vehicles” Is the Umbrella Test Guideline Document
- MIL-HDBK-343, “Design, Construction, and Testing of One of a Kind Space Equipment”
  - Applies risk criteria to MIL-STD-1540
  - Will be “reformulated” as the key SE SPO handbook for NSS systems

## *Associated Space Hardware Test “Guidelines”*

DOD-A-83577, “Moving Mechanical Assemblies For Space Vehicles, General Specification”

MIL-S-83576, “Solar Cell Arrays, Space Vehicle, Design and Testing”



### Other test specifications:

- DOD-E-83578B: Explosive Ordnance
- MIL-STD-1576: Electro Explosives
- MIL-STD-461: EMI
- MIL-STD-1541: EMC

MIL-STD-1522, “Requirements for Safe Design and Operation of Pressurized Missile and Space Systems”

# ***Standards Initiatives Have Re-emerged***

- **Mil-Std-1540 Space System Test Standard**
  - In the “industry coordination” phase as of this week
  - Intended to be compliance standard “on contract”
- **AIAA CPSRS**
  - Reviewing all space systems related standards/specs
- **AIAA CoS/RAVT Working Group**
  - Requirements, Analysis, and Verification and Test
  - Physical and environmental interfaces
  - Pre and post launch operations and processes
  - Mission assurance and risk management
- **International Standards Organizations (ISO)**
  - Multiple standards dealing exclusively with space systems
  - Down to the “Thou shalt” level

# ***SE-Related “Actionable” Recommendations***

- **Change Government Acquisition Policies to Address Appropriate Specifications, Standards, and Best Practices**
  - Not to be confused with the “old ways” of doing business
- **Develop an Experienced-Based SE Handbook for NSS SPOs**
  - Use MIL-HDBK-343 as a model
  - Address the acquisition life-cycle and program risk options
- **Develop an NSS Problem Information Sharing Network**
  - PMP Alerts
  - COTS hardware pedigree experience
- **Develop an NSS Lessons Learned System**
  - Critical lessons should be policy
- **Develop an Overarching NSS Best Practice Information Sharing System Linked to Appropriate Specifications, Standards, Lessons Learned and Alert System**



# *Overview*

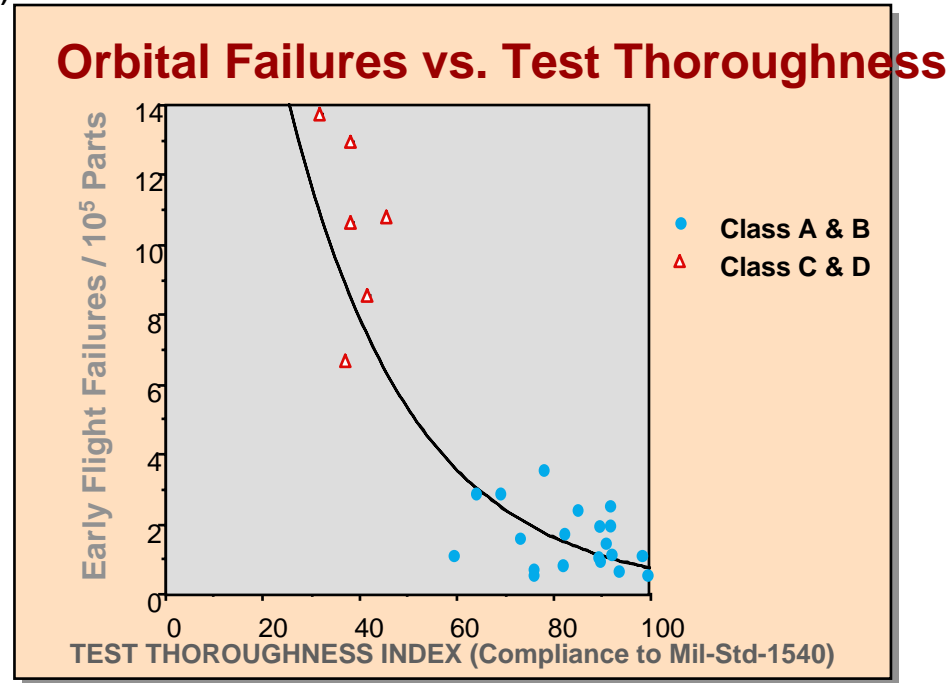
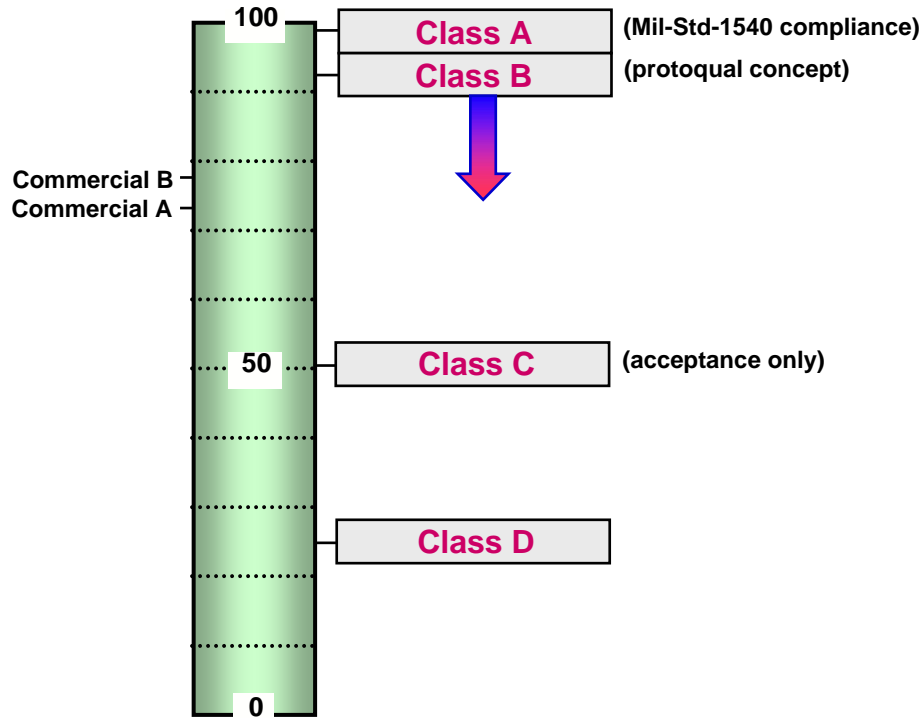
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# ***General Comments on T&E Trends***

- **Test Is Rarely Ahead of Advancing Technology, but Is Anticipatory and Reactive by Nature**
  - Tests are continually improved and revised to address:
    - » Technology unique problems
    - » Design margin robustness and new failure mechanisms
    - » Lessons learned
  - Unexpected issues are later incorporated into design changes, Specifications, Standards, and Best Practices as the result of lessons learned
- **The Need, However, for More Effective Test and Evaluation Practices is Growing Rapidly**
  - Hardware complexity is continually increasing
  - Software complexity issues are becoming more prevalent
  - Parts vendors no longer cater to high-rel customers
  - Loss of standards and less disciplined systems engineering practices

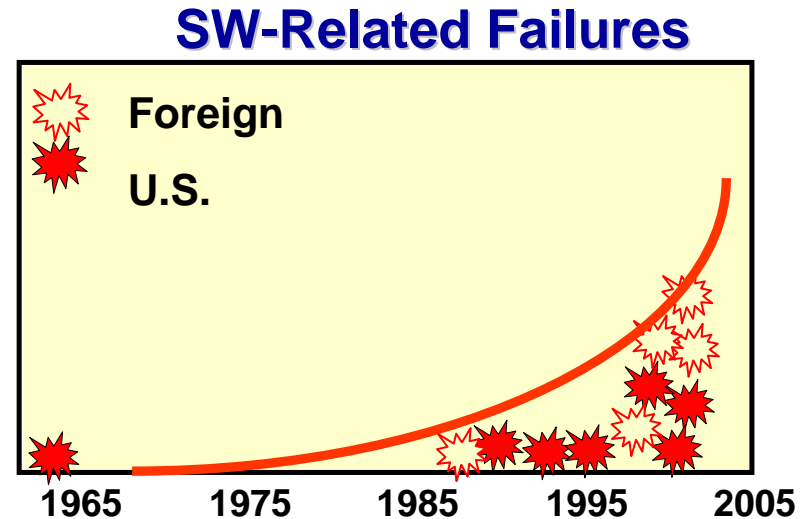
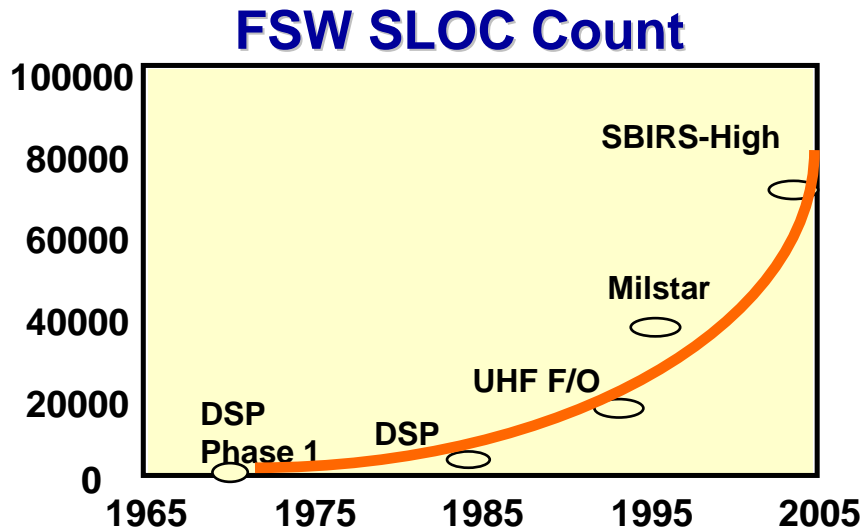
# Reducing Test Thoroughness Increases Risk of Failure

## Measure of Compliance with MIL-STD-1540



*Government and Commercial Testing Trends  
Are Less Conservative Than in the Past*

# *Software Increasingly Matters*



SOURCE: P. Cheng, The Aerospace Corporation.

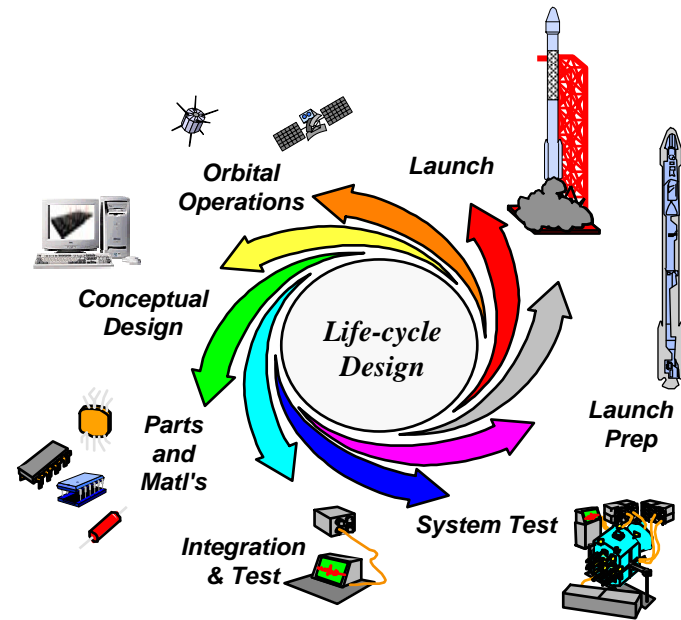
- Incomplete requirement implementation
- Improper s/w changes or code reuse
- Latent defects
- Inadequate configuration management

*As Complexity Increases, So Too Does the Tendency to Test in Orbit... Often with Unanticipated Consequence*

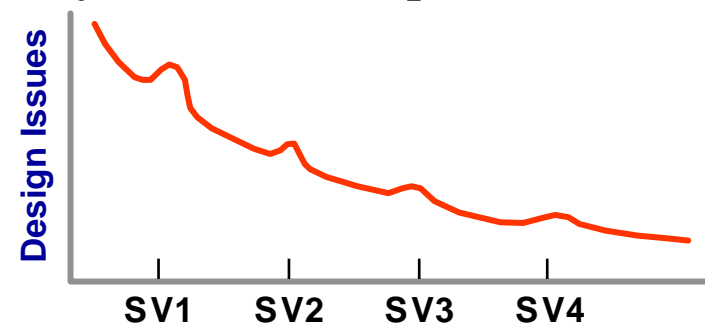
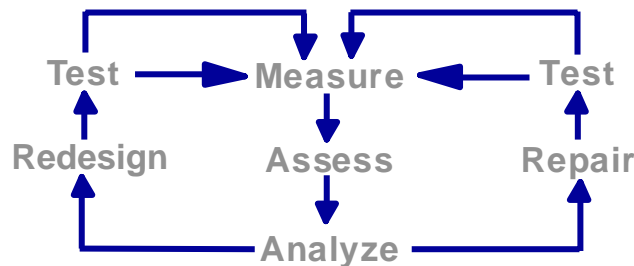
# *Test / Reliability / Data Feedback*

- **Continuous Feedback Is Key to Process Improvement in Era of Acquisition Reform**

- Factory
- Launch base
- Orbital experience
  - *Space environment*
  - *End of life mechanisms*
- “Cross-program experience”



- **NSSI Goal: *Improve the effectiveness of SE and T&E processes***



Time



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# ***T&E-Related “Actionable” Recommendations***

- **Form a Government Committee to Coordinate Executable Recommendation for Critical T&E Best Practices**
  - Establish government working group to identify cross-program T&E Best Practices
  - Evaluate T&E Best Practices identified from NRO Test Strategy Review
  - Sponsor updating of appropriate T&E spec/stds
- **Sponsor the Development of an Information Sharing System**
  - Develop government - contractor information sharing process
  - Sponsor development of computer-based deployment system
  - Sponsor annual government-contractor T&E workshop
- **Sponsor Cross-Program “Data Mining” Studies Across NSS Programs for T&E Process Improvement**
  - Begin with unit level thermal screening model
  - Identify T&E lessons learned for submittal to NSS Lessons Learned WG

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# 1. “T&E Best Practices” Initiative

## *Space Commission Recommendation:*

Align AF and NRO programs to adopt proven “best practices” for space research, development, acquisition and operations.

## *DoDD 5100.89:*

NSSI lead an effort to recommend T&E best practices and make them readily accessible across the NSS community to improve overall effectiveness.



## Undersecretary of the Air Force Action Plan:

- Government led team will evaluate and recommend a baseline set of proven T&E best practices
- Recommend process improvements to make T&E best practices accessible and executable throughout the NSS
- Coordinate and integrate where appropriate, BPT recommendations with other ongoing activities (e.g., SE reinvigoration, spec and standards updates, etc.)
- Present final recommendation and action plan to DoD Executive Agent for Space in June 2003



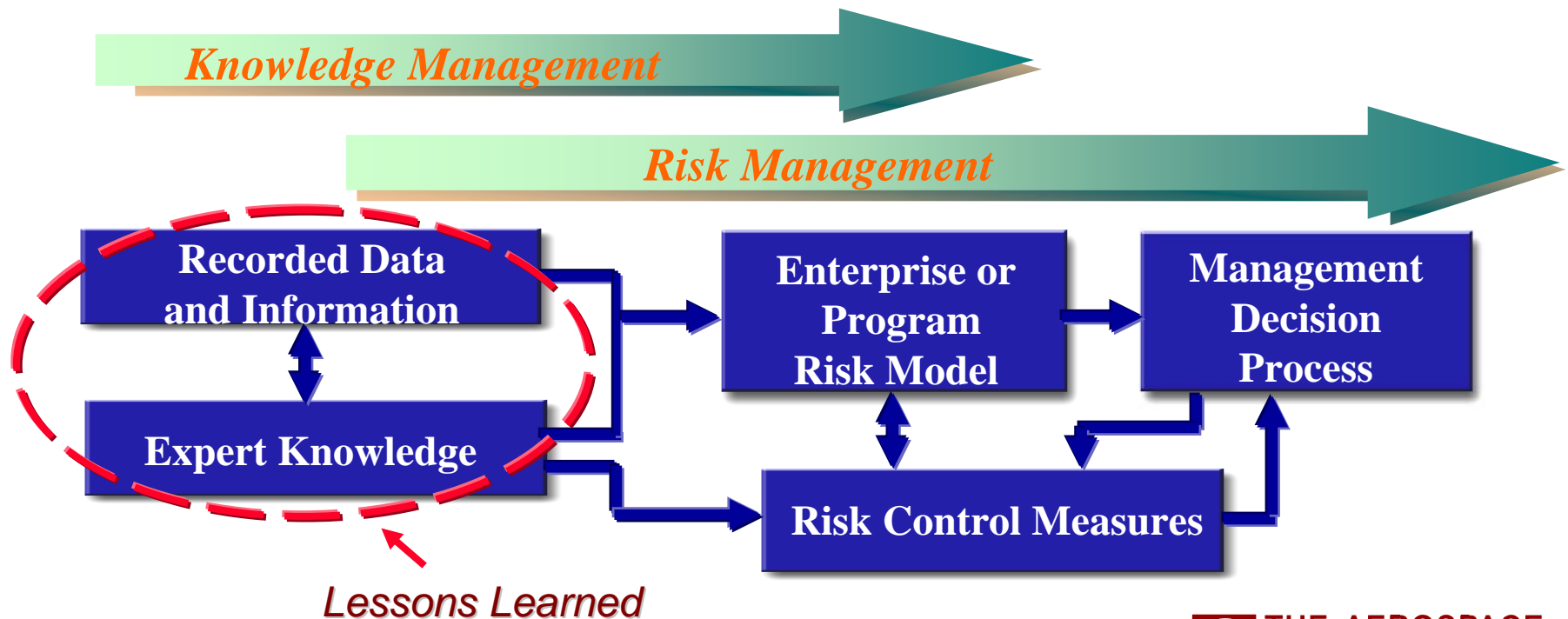
# ***Resurrecting Part of the SE Formulae***

- **The Formulae to Design, Develop, and Test Satellites and Launch Vehicles Were Mandated Out of Existence in the '90s**
- **What Remains Are Largely Guideline Documents**
  - Key standards are no longer maintained
- **Critical Lessons Learned in the Form of Commander's Policies Were Also Abandoned**
  - These are in the process of being resurrected
- **SMC-Aerospace Are Responsible for Maintaining the T&E Formulae (*relevant to Specs/Std*s) and Efforts Are Underway to Rekindle and Expand the Original Focus**
  - Database tools and data sharing
  - OSS&E policy implementation
  - Lessons learned process
  - Test standards and handbooks

# *Integrating Risk with Knowledge to Improve T&E and SE Processes*

- **Risk Management Deals with Uncertain Knowledge**

- Relies largely on experience of the past for future projection
- Formal risk assessment process and models enable higher confidence projection
- Risk management is speculative without some form of knowledge management



# ***Commander's Policies***

## ***- Previous Government Lessons Learned System -***

- **Commander's Policies Established in 1972**
  - Flight critical lessons learned became Center policies or AF regulations
  - **SAF/AQ Lightning Bolt #4 rescinded due to cost/oversight burden**
- **Proven Mission Assurance 1972-1995**
  - Example: Independent mass/control/stability analysis (SDR 550-4)
    - » No failures, 5 “diving catches” in SMC programs
    - » 7 failures in non-SMC programs
- **1999 Launch Vehicle BAR Attributed at Least Six Failures to Overlooking Lessons**
  - Tasked SMC/Aerospace to revitalize lessons learned process
  - Concerned with initial EELV risks

### **18 New LV Programs Since 1980**

<b><i>Launch Sequence:</i></b>	1st	2nd	3rd	4th	5th
<b><i>Success Rate:</i></b>	60%	70%	88%	100%	86%

## 2. “Lessons Learned” Policy Directive

### *LV BAR Recommendation 5:*

**Air Force makes SMC/CC responsible for timely, formalized mechanism to capture and disseminate lessons learned across programs and contractors**

### *LV BAR Recommendation 12:*

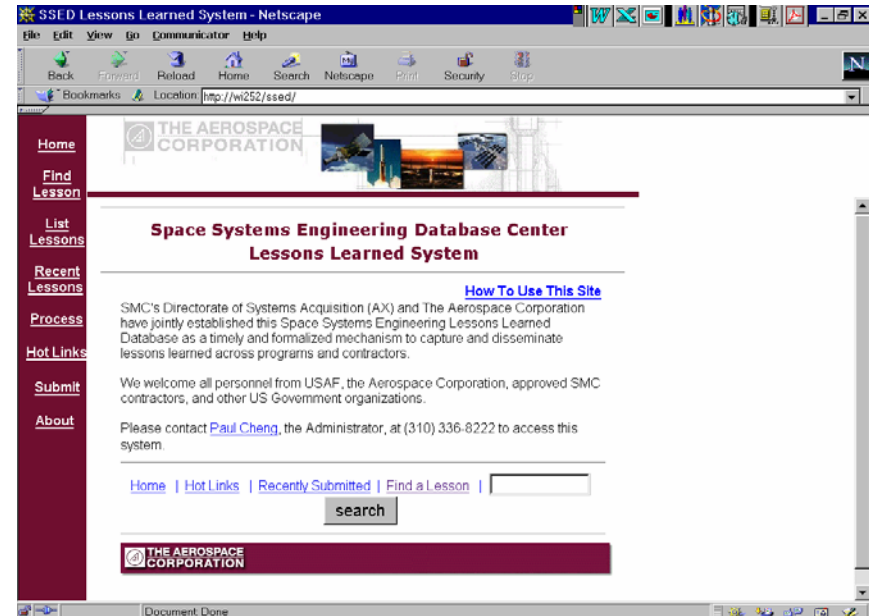
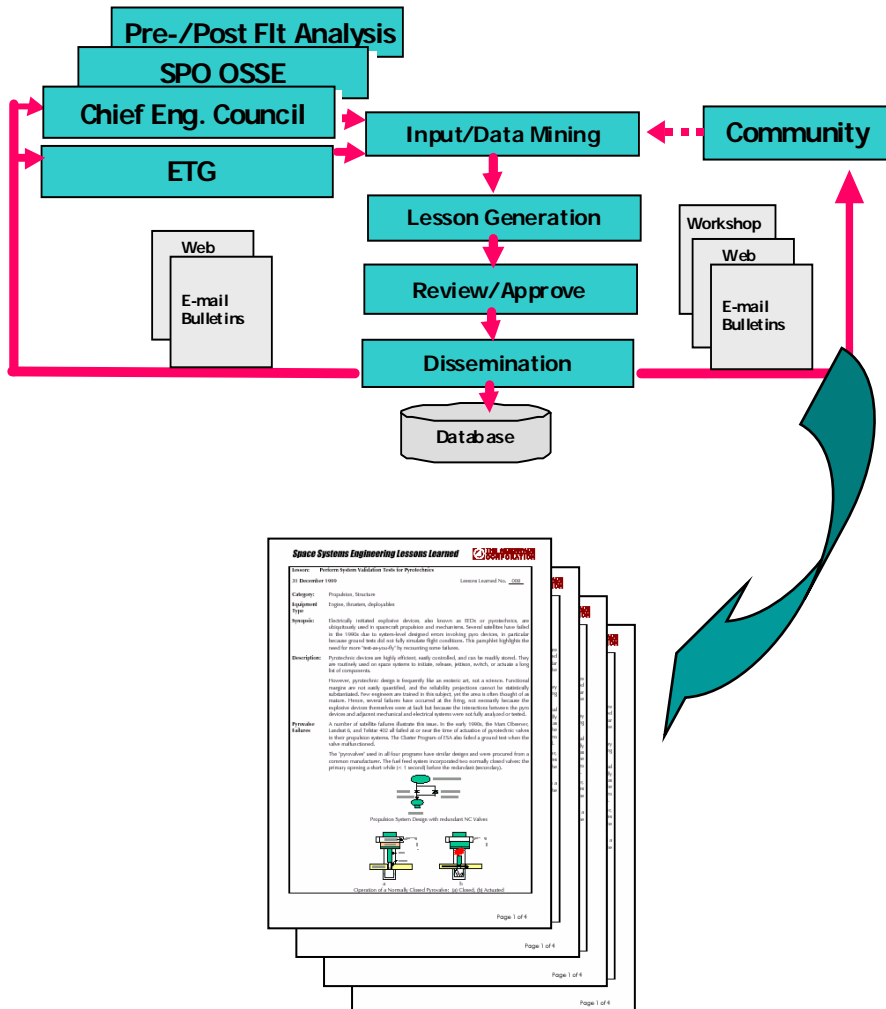
**Ensure lessons learned from heritage programs are applied to EELV**



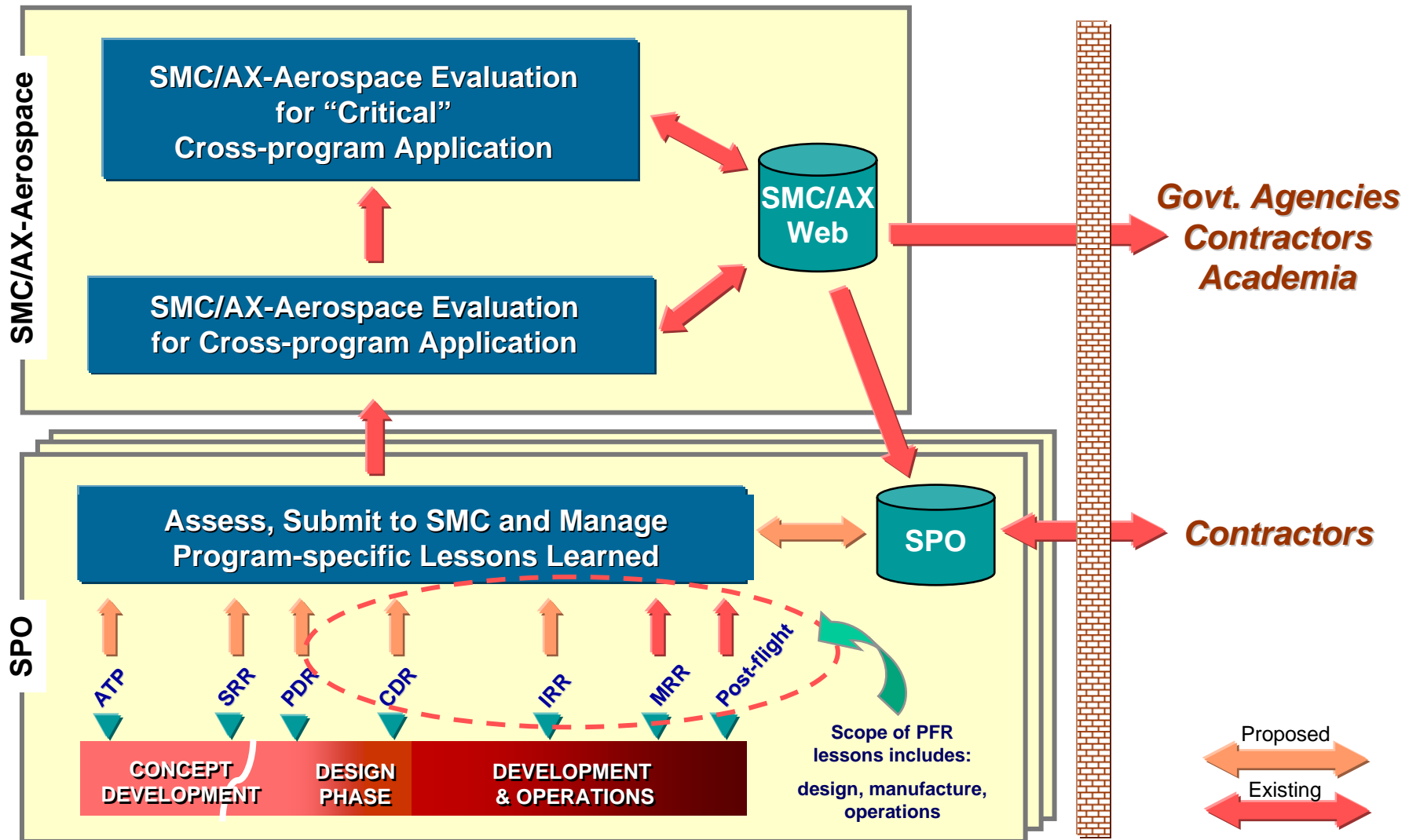
### **Air Force BAR Action Plans to SecAF (01/00):**

- Aerospace and contractors share lessons across SMC and NRO programs
- Capture and disseminate lessons learned across Center through SMC Chief Engineer Council
- Task SPO/Aerospace team to develop formal process and implement by 04/01/00
- Implemented via OSS&E Policy AFD 63-12 and SMCI 63-1201

# SMC-Aerospace Lessons Learned System Intended to Help Community Avoid Critical Mistakes



# Lessons Learned Process



# ***The Obstacle***

## ***Space Industry Test Experience Is Poorly Documented/Evaluated***

- **Catastrophes Are the Exception**
  - Challenger, Titan 34D, Leasat, Hubble Space Telescope...
- **Successful Test Programs Are Not Adequately Analyzed**
  - Why were they successful?
  - Would more testing have lead to greater success?
  - Would they have been equally successful with less testing?
  - Would different (less costly) tests have been equally or more successful?
  - What tests provide little or no added value?
  - Would more stressful testing at lower levels of assembly reduce overall costs?

# ***The Solution***

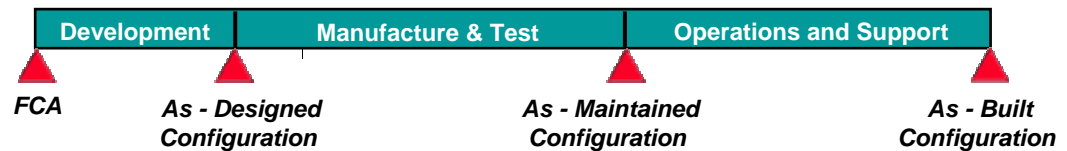
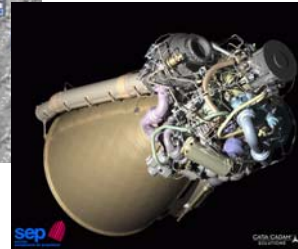
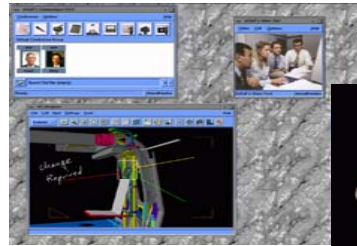
- **Collect, Study, Evaluate, Interpret Historical Pedigree, Failure, and Test Data From Past Launch and Space Vehicle Programs**
  - Embrace the principle of an integrated corporate database
- **Establish Standard Requirements and Procedures to Automate Acquisition of Data From New Programs – Add to Database**
- **Form Industry-wide Workshop to Share Lessons and Collaborate on Best Practices Related to Test and Mission Assurance Processes**
  - Develop optimized test models and requirements
  - Provide input for revision to “guideline” documents and standards
  - Develop improved methods to exchange critical problem alerts
  - Develop framework for empirical-based risk management solutions



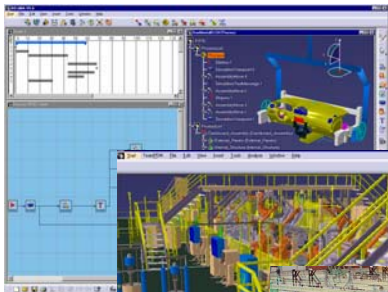
# Enterprise Information Management

## Leverage Cross-Program Knowledge to:

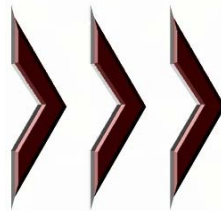
- Manage Risk
- Reduce Cost & Schedule
- “Mine” Lessons Learned
- Evaluate Test Effectiveness
- Improve Design
- Optimize Processes
- Prevent Defects



## Product Lifecycle Collaboration Tools



**DS**  
ENOVIA



**Integrated  
“Product-Process-Resource”**

**Seamless  
Requirements Traceability**

**Pedigree Assessment  
& Flight Certification**



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# ***EELV Mission Success Tenets***

## ***- Post LV BAR -***

- **Establish a Culture Where “Mission Success” is Everyone’s “Number One” Priority**
- **Reinvigorate System Engineering (SE) Process**
  - Emphasize SE Early in Development
- **Define Clear Roles & Responsibilities**
- **Manage Risk Systematically & Proactively**
- **Establish Solid Configuration & Process Controls**
  - Use clearly documented processes & procedures
- **“Test like you fly—fly like you test”**
- **Work to Eliminate Unverified Failures**
- **Conduct Independent Verification & Validation of Mission Critical h/w, s/w, and Processes**
- **Vigorous Post-Flight Analysis**
- **Capture & Leverage Lessons Learned**

# *Overarching Conclusions*

- **Government and Industry Pushed the “Risk Envelope” Too Far Without a Clear Roadmap**
  - The relationship between mission assurance and T&E was largely decoupled from SE
  - Risk management was and remains a fledgling discipline on many programs
- **Unrealistic Schedules, Cost, and Commercial Market Assumptions Resulted in Aggressive Cost Cutting or Risk Taking at the Same Time System Complexity Increased**
  - Many new systems about to be fielded fall into this category
- **“Mission Success First” is Clearly a Cost-Justified Goal**
- **NSS Is Taking Dramatic Steps to Reorient**

*Systems Engineering Needs to be a First Order Concern with “Strong” Management Buy-in*